[Proc. Roy. Soc. Victoria, 31 (N.S.), Part I., 1918].

Art. VII.—*The Significance of Lava Residuals in the Development of the Western Port and Port Phillip Drainage Systems.*

By ROBERT A. KEBLE

(Field Assistant, Geological Survey of Victoria).

(With 10 illustrations in the text)

[Read June 13th, 1918].

This paper is the outcome of several years of observation in the drainage systems of Western Port and Port Philip. As it affords the most typical instances of that topographical form—the lava residual, the development of which is the subject of the paper—the Western Port area, where it is a conspicuous feature, has perhaps received more attention. The Yarra has been navigated from above Launching Place to its mouth, a journey of over a hundred miles, and there is perhaps no better way of demonstrating the truth of the axioms of physiography than to experience their effect. From Launching Place to the Warrandyte Gorge, the Yarra, except at a small gorge just below the confluence of the Watts and the Yering Gorge, meanders over a flood plain, and is comparatively sluggish.

The Beaconsfield, Berwick, Pakenham, Gembrook, Woori Yallock, Nar-nar-goon, Tynong and Drouin districts, afford the most suggestive physiography; generally the Western Port area seems to furnish the key to much that is inexplicable in the Port Phillip area.

In treating with such an extensive area, I have been prompted on the one hand by the inseparable relationship of the one system to the other, and on the other hand, by the desire of formulating a general scheme of classification before attempting more detailed observations on smaller areas.

I.—Introductory.

The residual and its physiographical significance.
Previous work.
Bass Strait lava field.
Pre Older Basalt cycle of Western Port and Port Phillip systems.
Western Port and Port Phillip lava fields.

The Lava Residual and its Physiographical Significance.

Lava residuals (Fig. 1). or those particular topographical forms known by such more or less inappropriate terms as "high level

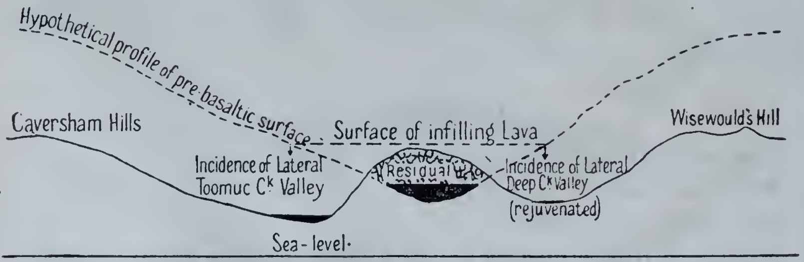


Fig. 1.

Section of a residual developed from a confined older Basalt lava field at Upper Pakenham.

leads," "high plains," or "volcanic plateaux," are the result of differential erosion—the greater resistance to erosion offered by basaltic lavas compared to the lesser resistance of the rocks contiguous to them. The development of a residual is characterised by three readily defined cycles of erosion. In the development of the Older Basalt lava residuals these cycles are as follows :—

(1) The Pre-Older Basalt Cycle, towards the close of which the stream system had reached a certain development (Fig. 3), with graded valleys probably for the most part of the mountain region type.

(2) The Older Basalt cycle extended over the period of volcanic activity during which the valleys of the previous cycle were occupied with lava for a considerable distance upstream, and a certain height above the pre-basalt stream. The lava confined between the pre-basalt watersheds of less resistant rocks, is referred to as a "confined lava field." At the locality down stream, where the lava overflowed these watersheds, an "extensive lava field" was formed. The period of volcanic activity was characterised by several short-lived and minor cycles of erosion at the conclusion of each flow, except that of the last one, which marked the beginning of the Intermediate cycle.

(3) The Intermediate Cycle inaugurated a new drainage system, for the lava of the second cycle had obliterated all traces of the previous drainage channels. The location of the new streams was guided by the position of the least resistant in regard to the more resistant rocks, and the direction of the gradient. Both of these conditions were fulfilled at the edges of the confined lava fields; consequently "lateral streams" (Fig. 1) started to cut back along these edges upward from the line of junction of the confined and extensive in lava fields.

Below this line of junction the new streams were compelled to carve out valleys on the resistant basaltic lava and assumed directions quite irrelevant to the submerged watersheds. The watersheds, however, being covered by the least thickness of lava, and, consequently, the lines of least resistance, were eventually exposed by vertical erosion. (Fig. 2.) Tributaries commenced to cut back

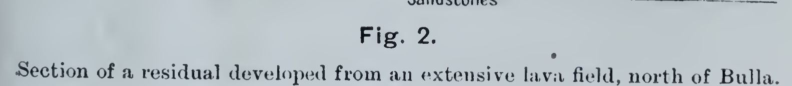


Fig. 2.

Section of a residual developed from an extensive lava field, north of Bulla.

along them and assisted by a system of domestic piracy, with comparative rapidity, became the main streams with the original streams as tributaries. These new streams thenceforth assumed the characterstics of lateral streams.

The widening of the lateral streams had the effect of gradually restricting the width of the residuals. Tributaries of lateral streams (termed "minor laterals"), having their source on and cutting back into a residual, tended ultimately to sever it into a number of isolated residuals, which became more and more isolated as the streams in question developed. A stream that has actually breached a residual is termed a "cross stream." During the Intermediate cycle the lateral streams, and their tributaries have been again and again rejuvenated by oscillation of the land surface, faulting and capture, and both lateral and cross streams have repeatedly deepened and widened their valleys. The Pre-Older Basalt stream levels are in many cases hundrds of feet above that of the neighbouring lateral streams, hence the use of the term "high level lead." Nearly all the residuals north of the railway from Melbourne to Drouin are conspicuous features, and many of the stream deposits or "leads" below them have been worked for gold.

To the west and north of Melbourne, however, the development of residuals from the Newer Basalt lavas is in progress. The valleys of the Intermediate cycle have been occupied or flooded by lava, and both confined and extensive lava fields have resulted. The development of these Newer Basalt residuals was likewise characterised by three cycles corresponding to the first, second, and third just mentioned, namely :—

(3) The Intermediate cycle just considered,

(4) The Newer Basalt cycle during which confined and extensive lava fields were formed in or above the lateral valleys of the Intermediate cycle, and

(5) The Post Newer Basalt cycle, at the beginning of which a new system of drainage was initiated, and is beginning to develop a system of lateral streams. Minor laterals are common, but as evidencing the fact that the development of the residual is in a youthful stage, it is significant that cross streams are correspondingly rare, in other words, the Newer Basalt residuals have only at few localities been breached.

Previous work.

The first notice of a lava residual seems to have been by Mr. R. A. F. Murray,[1] who, more than thirty years ago, described those at Dargo. He clearly recognised their physiographical significance, and commented on the condition of the ancient valleys immediately preceding the issue of the older lavas, indicating, among other interesting facts, the direction of the valleys. The sections illustrating the paper show the profiles of the pre-Older Basalt valleys.

Later, Messrs. S. B. Hunter,[2] A. M. Howitt,[3] and others, described and sectioned residuals in the north-east portion of Victoria, and showed them to possess characteristics in common with those at Dargo.

At a later date, Mr. Murray[4] sectioned the residual at Upper Pakenham, and indicated its bearing on the local physiography. This residual is typical of one evolved from a confined lava field, and from data that have since accumulated I have attempted another section.

At a still later date Prof. Gregory[5] sectioned the Kangaroo Ground residual.

From a physiographical standpoint, Mr. J. T. Jutson's several papers[6] cover much of the area dealt with in this paper; Prof. Gregory,[7] in a broad way, has treated on the whole of it; while Messrs. N. R. Junner,[8] T. S. Hart,[9] M. Morris, [10], and Dr. T. S. Hall,[11] and Dr. G. B. Pritchard[12] have from time to time commented on portions of it.

Reference will be made to these several contributions where the context requires it.

Bass Strait lava field.

The lava that partly occupied the ancient drainage systems of Western Port and Port Phillip is the northern fringe of a lava field that has for the most part been submerged by the waters of

1 Vide Bibliog., No. 16.
2 Ibid., No. 10.
3 Ibid., No. 9.
4 Ibid., No. 17.
5 Ibid., No. 4.
6 Ibid., No. 12 and 13.
7 Ibid., No. 4.
8 Ibid., No. 11.
9 Ibid., No. 7.
10 Ibid., No. 15
11 Ibid., No. 5.
12 Ibid., No. 19.

Bass Strait. The southern fringe is found at various localities on the north coast of Tasmania, its eastern fringe is probably in the vicinity of the partly submerged range between Wilson's Promontory and the north-east coast of Tasmania, and its extension westward is problematical.

As a necessary premise to the evolution of erosional forms on the mainland, it is assumed that Harker's[1] assertion relating to gradient, applied to the Bass Strait lava field. According to Harker, the surface of a lava stream has a certain inclination depending mainly on its viscosity and rapidity of cooling, but the actual gradient is very slight in the case of a stream of large volume. He quotes well-known examples from different parts of the world.

The eruption of Laki, on the south-west coast of Iceland, is an example within historic times, for in 1783 an old fissure re-opened for twenty miles and streams of basalt welled out from a number of new cones. The confluent lava streams formed floods which flowed over the surrounding country, and down two valleys —in one of which it travelled fifty miles, and was in places from twelve to fifteen miles in breadth, and eight hundred feet deep. The present volcanic activity of Iceland dates from the Eocene, and is supposed to be connected with the lava field of Antrim, which extended far within the Arctic circle. In Iceland it exceeds a thickness of 5000 feet.

The Columbia lavas of the United States are from two hundred to two hundred and fifty thousand square miles in extent, and have a maximum thickness of four thousand feet. The lava fields of the Deccan, Hawaii, Colorado and other areas may also be cited. An area in which the lava is in many respects in a similar stage of erosion to the Older and Newer Basalt lava residuals of Victoria is that the Uinkaret, described by Dutton[2] in his Monograph of the Grand Canyon district.

The Older basalts of Victoria[3] are assumed to have issued from eruptions mainly of the fissure type. Dykes and pipes have been found in various parts of the area by Messrs. Ferguson,[4] Chapman and Teale,[5] Ower, and others. It matters little to the general

1 Vide Bibliog., No. 6.

2 Vide Bibliog., No. 2.

3 Prof. Skeats commented on the Tertiary basalts in his Presidential Address to the Brisbane Meeting of the Australasian Association for the Advancement of Science for 1909. Bibliog., No. 20.

4 Bibliog., No. 3.

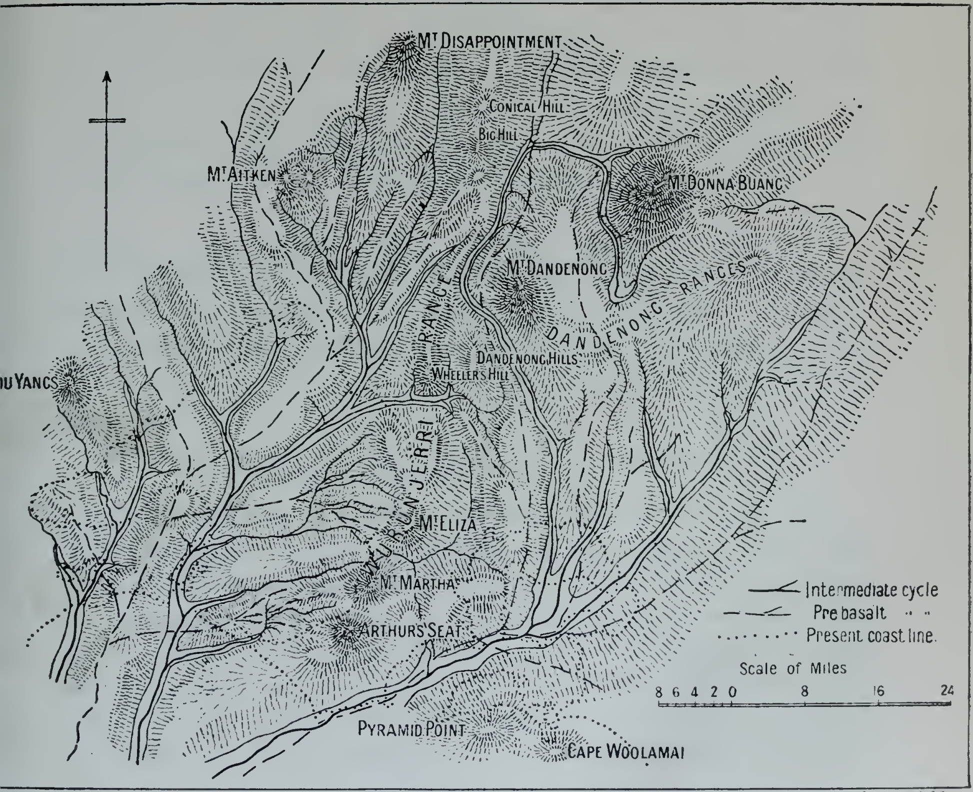
5 Ibid., No. 1.

6 Ibid., No. 18.

conclusions arrived at in this paper how the lava was extravasated, or whether the crustal movements responsible for it were of the mountain or plateau building types. What is more important from the standpoint of the physiographer and palaeographer is to reconstruct the lava field as it was at the cessation of volcanic activity, and only volcanic phenomena essential to this reconstruction are considered. The Older and New Basalt residuals afford, it is submitted, the necessary data for this reconstruction.

Pre-Older Basalt cycles of Western Port and Port Phillip.

Portion of the Western Port system during the Pre-Older Basalt cycle was, as it is now, a mountain region. The same factors that made it so then are in operation now, namely, highly resistant metamorphic rocks at the contact of Palaeozoic granitic and



Drawn by A.E.B

Fig. 3.

New basalt valleys of pre basalt cycle. These valleys were infilled with the older basalt which precipitated the intermediate cycle.

sedimentary series, and massifs of almost equally resistant dacite, also of Palaeozoic age. The Older Basalt and Newer Basalt are of Tertiary age.

If the large stream[1] that flowed in the vicinity of Klingsporn's Station,[2] Wood's Point, Mt. Leckie, Drouin, Lang Lang, French Island, Flinders and Cape Shanck had its source at Mount Buller and its outlet somewhere near Flinders Island in Bass Strait, as the bathymetrical contours would suggest, only its headwaters are represented in the 130 miles now above sea level. The most mountainous part of its course was between Mt. Buller and Drouin, and in the vicinity of Flinders. Bearing in mind that the mature erosion of a mountain region, which a reconstruction of the residuals appears to suggest, is characterised by steep declivities rising sometimes thousands of feet above the flood plain, one may comprehend much that seems unusual from the two thousand feet of lava assumed to have existed at Flinders from the evidence of a bore, and the amount of denudation disclosed by the slope above it. Perhaps the valleys of the Kiewa, Buckland, and other streams in the north-east province of Victoria are comparable to the Pre-Older Basalt stream just mentioned; they are typical examples of erosion in a mountain region; and meander over well graded flood plains.

The erosion of the Port Phillip system during the Pre-Older Basalt cycle was affected by different considerations. There were no dacite massifs, and the contact metamorphic rocks were so disposed that large areas of the less resistant rocks permitted a rapid development of the stream system.

Western Port and Port Phillip lava fields.

With data forthcoming from the sections of residuals (Fig. 4), their configuration (Fig. 9), disposition, and the trend of "uncovered residuals,"[3] a reconstruction of the surface of the Western Port and Port Phillip lava fields is possible. This reconstruction (Fig. 4) shows that at the cessation of volcanic activity the valleys of the Pre-Older Basalt cycle were occupied in their upper portions by long tongues of lava (confined lava fields), which merged southwards into a more extensive plain (extensive lava field). South of

1 Ostensibly, Prof. Gregory's Tarago, vide Bibliog., No. 4.

2 Klingsporn's Station is situated south-west of Mount Buller, between the Howqua and Jamieson Rivers. The area of older Basalt representing the residual has never been charted.

3 Vide p. 147, post et fig. 8.

PORT PHILLIP SYSTEM.

	Spotswood.		Mordialloc.		Lang Lang.	
Post Newer Basalt Cycle			Clays and sands	223.0		
New Basalt Cycle	Basalt	29.0			Clays, sand and drift	
Intermediate Cycle	Blue calcareous and lignitiferous clays	141.0				
Older Basalt Cycle	Basalt	83.3	Basalt	17.0	Basalt, more or less decomposed	
	Basaltic clay and ash	6.9			Basalt, hard and dense	
					Basalt, vesicular	
					Lignitiferous sands, clays and drifts	
					Basalt, hard	
Pre Older Basalt Cycle	Clay	14.0			Lignitiferous clays and drift	1[illegible]
	Sand, with pebbles and lignitiferous material	22.0				
	Sand and large pebbles	26.6				
Palaeozoic or Mesozoic		7.6				[illegible]
Total depth bored		330.0		240.0		[illegible]

Corinella.		Phillip Is.		Flinders		Cape Schanck.	
and clays	330.6	Sands and clays	12.0	Surface soil dark	1.0	Surface sand and clay	9.6
				Clay, yellow	20.6	Basalt rubble and boulders	6.0
lt	47.6	Basaltic clay	69.9	Basalt decomposed	112.0	Basalt, concretionary hard	18.0
		Basalt, hard	71.6	Basalt hard, jointy, with decomposed layers	843.0	Basalt decomposed	63.6
		Clay, basaltic	9.6	Clay basaltic	176.0	Basalt, portions dense, portions decomposed	271.9
		Basalt	23.9	Basalt, hard, broken	20.6	Basalt gravel and conglomerate	8.9
				Basalt decomposed and balsaltic clays	127.0	Clay, basaltic red and grey	187.0
						Basalt crushed and broken in places	178.6
						Clay and decomposed basalt, glicken sided in places	69.0
						Basalt	48.0
ds and clays	68.0						
	536.0		169.0				
	982.0		356.0		1300.0		860.0

a line, represented approximately by the railway line between Melbourne and Drouin, this extensive lava field was more than thirty miles wide, but converged towards Flinders, and passed through the bottle-neck there on to the now submerged area of Bass Strait. The confluence of the confined and extensive lava fields approximately in the vicinity of the railway line, marked a change in gradient due in the first place to lava streams being confined within the comparatively narrow limits of the valleys, and in the second, to the lava rising above the watersheds and flooding an extensive area.

So much of the Port Phillip lava field is buried beneath the Upper Tertiary lavas and sedimentary deposits, or submerged under the waters of Port Phillip Bay, that the evidence for reconstructing it is less direct than that of the Western Port area. The sections available seem to indicate that the several tributaries joined the trunk stream at more regular intervals than those of the Western Port system, and as a consequence the valleys were more evenly graded. That a considerable volume of lava poured down the main valleys is evident from the thickness still existing in the vicinity of Essendon and Bellarine. It probably first began to flood the watersheds in the vicinity of the railway line between Melbourne and Drouin. Older volcanic lavas were pierced by bores at Mordialloc and Frankston.

From considerations of viscosity and cooling, it is obvious that lava flows confined to valleys and regulated as the Western Port flows were by a single outlet, are relatively thick compared to those that have welled out and flowed over a plain surface, as the lava did once the pre-existing watersheds were flooded, and an extensive lava field was formed. The implication is that wherever the valleys were restricted the lava was to some extent banked up, resulting in a greater thickness and extent of lava at and upstream from the bottle-neck. Such a circumstance is implied by the Flinders and Gembrook bottle-necks; the accumulation of lava at these localities has had a profound effect on the subsequent development of the streams of the Intermediate cycle by retarding it, and in the case of the streams above the Gembrook bottle-neck, reversing their direction. Bottle-necks undoubtedly marked a great change in the gradients of the lava fields.

The gradient was materially affected by the proximity of a vent or fissure to the valley. Prof. Skeats suggests[1] that if a vent or

---

1 Verb. cit.

fissure opened in or across the valley, a portion of the lava may have found its way up the valley, in which case the point of issue would also mark a change in the gradient of the lava fields. There seems to be evidence of this to the north of Gembrook.

The following is a tabulation of the strata passed through by several bores put down by the Mines Department. The correlation of the strata into their respective cycles is my own.

"High level leads," or the beds of streams belonging to the Pre-Older Basalt cycle, have been worked for gold at Gembrook, Hoddle's Creek, Wandin, Upper Pakenham, Neerim, Mt. Leckie, Lilydale and numerous other localities. The Quarterly Reports of the Mining Registrars for the first and second decades after the discovery of gold in Victoria, contain many references to these "high level leads," and the difficulties encountered in working them. The main difficulty was what is termed by miners "loss of level," due to an inadequate conception of the depth of the valleys and their trend; they often failed to tunnel into the lead at a sufficient depth to get under it, a necessary procedure to ensure efficient drainage.

At Wilson's Quarry, in the Berwick residual, there is a thickness of about seventy feet of lava. In the floor of the quarry leaf beds are exposed, below which again is the bed of an old stream belonging to the Pre-Older Basalt cycle. This old stream undoubtedly rests on Palaeozoic slates and sandstones, which are exposed in the quarry.

Alternating steep and gentle slopes of certain residuals suggest the intercalation of softer strata, but if these softer beds were numerous or of appreciable thickness, sections of residuals would correspond to the mesas of the Grand Canyon district of Colorado,[2] to which they bear little resemblance.

A survey of the evidence derived from borings and sections seems to permit of the following inferences:—

(a) That from the outbreak to the cessation of the Older Volcanic activity there were periods of quiescence indicated by intercalated clays and sands.

(b) That compared to the subsequent erosion, and accumulation of sediments in the lateral valleys, these periods of quiescence were of short duration.

---

1 Vide Bibliog., No. 14.

2 Vide Bibliog., No. 2. "The Uinkaret."

It is not known, however, whether the clays between the lava flows were residual[1] or transported, or whether they represent the whole or only part of them. These and other pertinent considerations arise, but the inference seems tolerably safe that the period of volcanic activity was comparatively short compared with that of the Intermediate cycle between the Older and Newer Basalt. From such a point of view these phases of volcanic activity are of great stratigraphical and physiographical value, marking, as they do, the termination and inception of three great cycles of erosion —the Pre-Older Basalt, the Intermediate, and the Post Newer Basalt.

Some stress has been placed on the use of such terms as "older basalt" and "lower newer basalt," but I venture to think, especially as the same flow is designated by both symbols, that only one period is meant. The use of the two symbols has probably arisen from the points of view of the two observers, one of whom considered it to belong to the close of the Miocene and the other to the beginning to the Pliocene.

Mr. Jutson[2] thinks that there is some reason, on lithological grounds, for establishing an intermediate period of volcanic activity. The complications arising from the assumption of an intermediate flow are referred to in another part[3] of this paper.

II.—Evolution of a Residual from a Confined Lava Field.

Stages of Evolution.

At the beginning of the Intermediate cycle the valleys towards their headwaters contained long and narrow lava fields flanked by watersheds of less resistant rocks. The streams of the two previous cycles were submerged beneath the Older Basalt so that the drainage of the Intermediate cycle was forced to seek new outlets. The development of the new drainage system was guided by two factors, namely, the direction of highest gradient, and the line of least resistance, conditions that were at once fulfilled by the comparatively unresistant rocks at one or both edges of the lava.

The resistance of the rocks flanking a residual affords a means of classifying them. They severally belong to one of the following stages :—

---

1 Mr. Ower, Assistant Boring Engineer of the Geological Staff, assures me that the intercalated clays in the Flinders and Cape Schanck bores were residual.

2 Vide Bibliog., No. 13.

3 Vide p. 143, post.

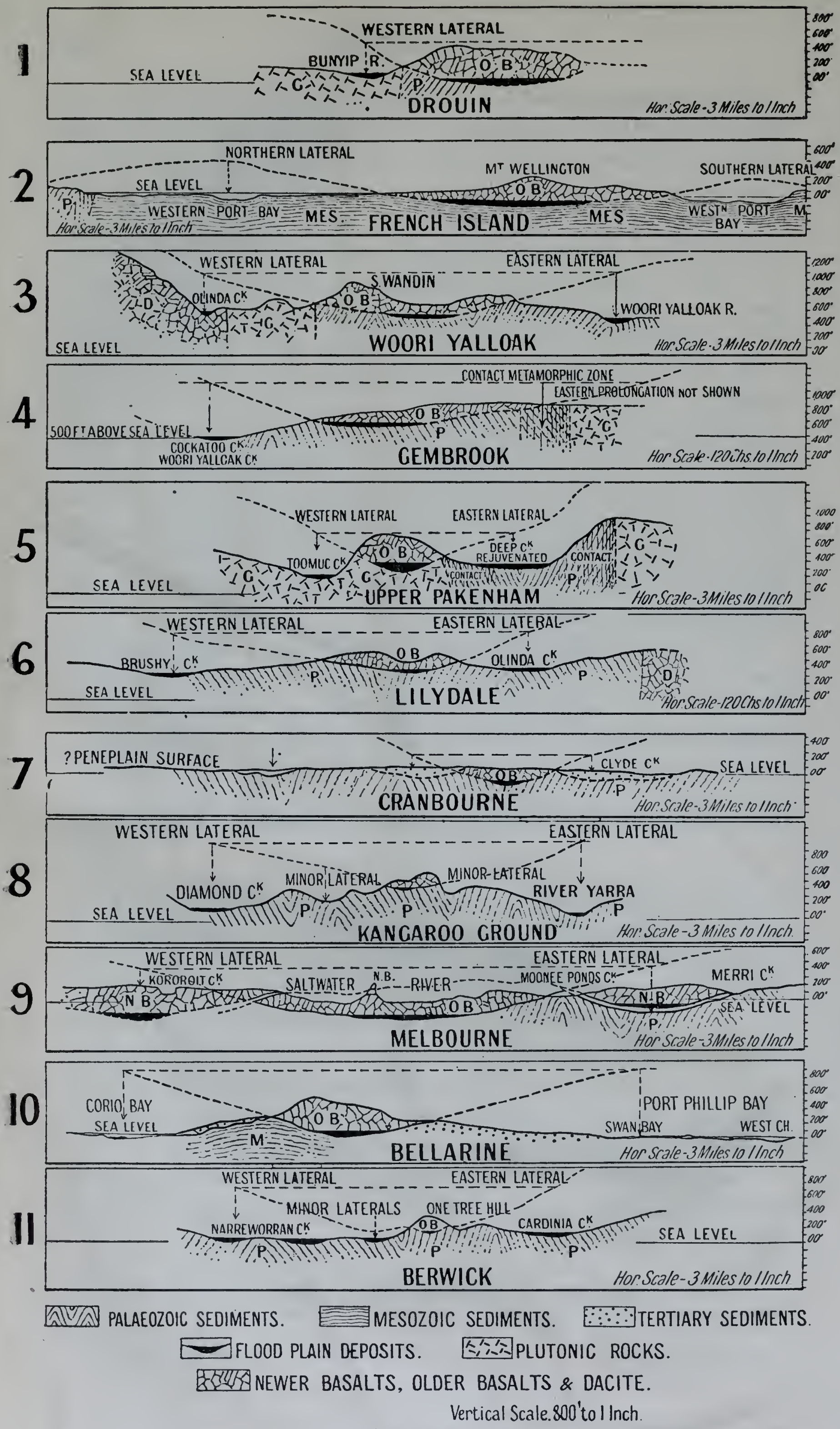

1
WESTERN LATERAL
BUNYIP R.
O B
SEA LEVEL
C
P
DROUIN
Hor. Scale - 3 Miles to I Inch
2
NORTHERN LATERAL
MT WELLINGTON
SOUTHERN LATERAL
SEA LEVEL
O B
P
WESTERN PORT BAY
MES
FRENCH ISLAND
MES
WESTN PORT BAY
M
Hor. Scale - 3 Miles to I Inch
3
WESTERN LATERAL
EASTERN LATERAL
S. WANDIN
D
OLINDA CK
O B
C
WOORI YALLOAK R.
SEA LEVEL
WOORI YALLOAK
Hor. Scale - 3 Miles to I Inch
4
CONTACT METAMORPHIC ZONE
EASTERN PROLONGATION NOT SHOWN
O B
500 FT ABOVE SEA LEVEL
P
C
COCKATOO CK
WOORI YALLOAK CK
GEMBROOK
Hor. Scale - 120 Chs. to I Inch
5
WESTERN LATERAL
EASTERN LATERAL
O B
DEEP CK
REJUVENATED
TOOMUC CK
CONTACT
G
C
SEA LEVEL
UPPER PAKENHAM
Hor. Scale - 3 Miles to I Inch
6
WESTERN LATERAL
EASTERN LATERAL
O B
BRUSHY CK
OLINDA CK
P
D
SEA LEVEL
LILYDALE
Hor. Scale - 120 Chs to I Inch
7
? PENEPLAIN SURFACE
CLYDE CK
SEA LEVEL
OB
P
CRANBOURNE
Hor. Scale - 3 Miles to I Inch
8
WESTERN LATERAL
EASTERN LATERAL
MINOR LATERAL
MINOR LATERAL
DIAMOND CK
RIVER YARRA
SEA LEVEL
P
KANGAROO GROUND
Hor. Scale - 3 Miles to I Inch
9
WESTERN LATERAL
EASTERN LATERAL
KOROROIT CK
SALTWATER
N.B.
RIVER
MOONEE PONDS CK
MERRI CK
N B
O B
SEA LEVEL
P
MELBOURNE
Hor. Scale - 3 Miles to I Inch
10
CORIO BAY
SEA LEVEL
O B
M
PORT PHILLIP BAY
SWAN BAY
WEST CH.
BELLARINE
Hor. Scale - 3 Miles to I Inch
11
WESTERN LATERAL
EASTERN LATERAL
MINOR LATERALS
ONE TREE HILL
NARREWORRAN CK
OB
CARDINIA CK
SEA LEVEL
P
BERWICK
Hor. Scale - 3 Miles to I Inch
PALAEOZOIC SEDIMENTS.
MESOZOIC SEDIMENTS.
TERTIARY SEDIMENTS.
FLOOD PLAIN DEPOSITS.
PLUTONIC ROCKS.
NEWER BASALTS, OLDER BASALTS & DACITE.
Vertical Scale. 800' to I Inch.

Fig. 4.

(a) Residuals due to the erosion of rocks of varying resistance flanking the protective lava beds, the rocks on one flank being a little more resistant than the lava. One lateral valley has formed, as in the Gembrook residual (Fig. 4[4]), but the other will subsequently form, or is in process of formation, as in the Woori Yallock residual (Fig. 4[3]).

(b) Residuals where the flanking rocks are more resistant on one side, but somewhat less resistant than the lava. Erosion is facilitated on one side and retarded on the other; consequently one lateral valley approaches maturity more rapidly than the other. The Upper Pakenham and Lilydale residuals are examples (Fig. 4[5 & 6]).

(c) Residuals due to the erosion of relatively feebly resistant rocks flanking the hard lava. If the flanking rocks are of relatively uniform resistance the lateral valleys are of equal importance. The Berwick residual is typical of this stage. (Fig. 4.[11]).

From the fact that the resistance of the flanking rocks is always variable, even in the case of a residual developed under the conditions outlined for stage (c), all pass successively through the above development stages. Concisely the three stages may be taken to represent the orderly evolution of a residual from a confined lava field, and are successive stages in the process of denudation, the object of which is to reduce the lateral streams to base level, and, incidentally, remove by lateral planation the lava protection.

Relative Resistance to Erosion.

In descending order of decreasing resistance to erosion, the rocks of the Western Port and Port Phillip areas may be tabulated as follows:—

Firstly—Metamorphic rocks at their actual contact with igneous rocks of Palaeozoic age.

Secondly—Volcanic rocks.

- (a) Dacite, andesite, etc., of Palaeozoic age.
- (b) Lavas of the Newer Basalt.
- (c) Lavas of the Older Basalt.

Thirdly—Plutonic rocks.

Granites, granodiorites, syenites, etc., of Palaeozoic age.

Fourthly—Sedimentary rocks.

(a) Palaeozoic sandstones shales and slates.
(b) Jurassic sandstones and shales.
(c) Tertiary sediments.
(d) Decomposed igneous rocks, particularly the lavas of the Older Basalt.

It will be recognised that the structure and physical characteristics of these several rocks modify their powers of resistance. The metamorphic rocks, placed above as the most resistant, merge into one of the least resistant at a variable distance from the actual contact; they retain more or less of their tectonic structure, and in this respect are subject to the same erosional factors as their unaltered representatives. Igneous rocks decrease in resistance according to whether they are vitreous, hypocrystalline or holocrystalline. The marked difference in resistance between those secondly and thirdly tabulated seems to be due to this rather than to any decided dissimilarity in chemical composition. The Palaeozoic sediments as a whole offer little resistance compared to the igneous rocks, but their sandstone members are sometimes more resistant than some igneous rocks.

Short cycles of erosion during Volcanic activity.

Short cycles of erosion were initiated at the beginning of the comparatively brief periods of quiescence between the lava flows comprising the Older Basalt, and lateral streams commenced to cut back from the changes of gradient at the edge of the confined lava fields. Erosion had not proceeded to any extent before another lava flow filled in the young valley, and a new cycle commenced at the edge of the last flow. Infilling and erosion thus proceeded hand in hand until a cycle of erosion—the Intermediate —proceeded uninterrupted. The inferences arising from this sequence of events is both interesting and important. A section (Fig. 5) will better illustrate the possibilities arising from it.

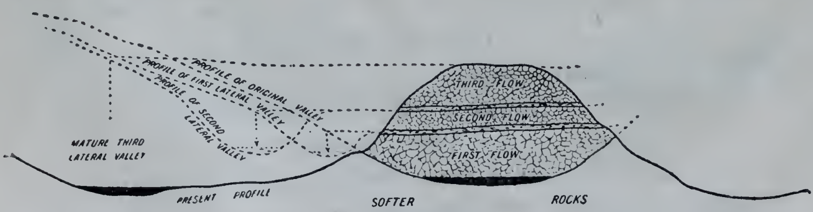


Fig. 5.

Erosion succeeding three consecutive lava flows with a comparatively short space of time between them. Hypothetical Section.

Fig. 5 shows the erosion succeeding three consecutive lava flows with a comparatively short period between them. The same amount of lava is supposed to be represented by each flow. Note the "turtle shape" (to use Dutton's[1] term) of the residual.

Now let us suppose that another series of lava flows has welled out and occupied graded lateral valleys initiated at the close of the Older Basalt. This is so as regards the Melbourne residual (Fig. 4[9]), where the Newer Basalt has occupied valleys belonging to the Intermediate cycle and initiated a new cycle—the Post Basalt cycle. This new cycle has proceeded on the same lines as the Intermediate cycle and lateral streams, namely the Merri and Moonee Ponds Creeks, have been formed at the edges of the confined Newer Basalt field. The western edge of the residual is flanked by the Newer Basalt extensive lava field, and the Saltwater River is in the unique position of being a lateral to an extensive lava field formed on the little resistant decomposed lava of the Older Basalt.

If an intermediate phase of volcanic activity had occurred the Newer Basalt instead of occupying the lateral valleys of the Older Basalt residuals, would be occupying the lateral valleys of this supposed intermediate lava, and a complicated system of erosion would have resulted at the inception of the Newer Basalt cycle.

Main lateral streams. Beginning of the Intermediate cycle.

Erosion commenced simultaneously on the softer rocks flanking the confined lava field and on the lava field itself. The resistance of the latter, however, soon threw (Fig. 6) the incidence of erosion on to the less resistant flanking rocks, where it will remain until the residual disappears by lateral planation. The streams that formed on the lava field were quickly captured by the lateral streams on the less resistant rocks; the indented configuration, exhibited by many residuals in plan, is due to the cutting back of these captured streams. Until the lateral streams assumed a mature aspect, the talus boulders broken away from the lava by sapping had a powerful abrasive effect in corrading and gouging out the lateral valleys. As, however, the talus slopes became graded, much of their force was expended on the reduced talus slope. Talus boulders may be seen at the edge of the lava at Harkaway where, from large angular ones at the edge and smaller subangular ones down the slope, they ultimately become small and rounded still further away.

1 Vide Bibliog., No. 2.

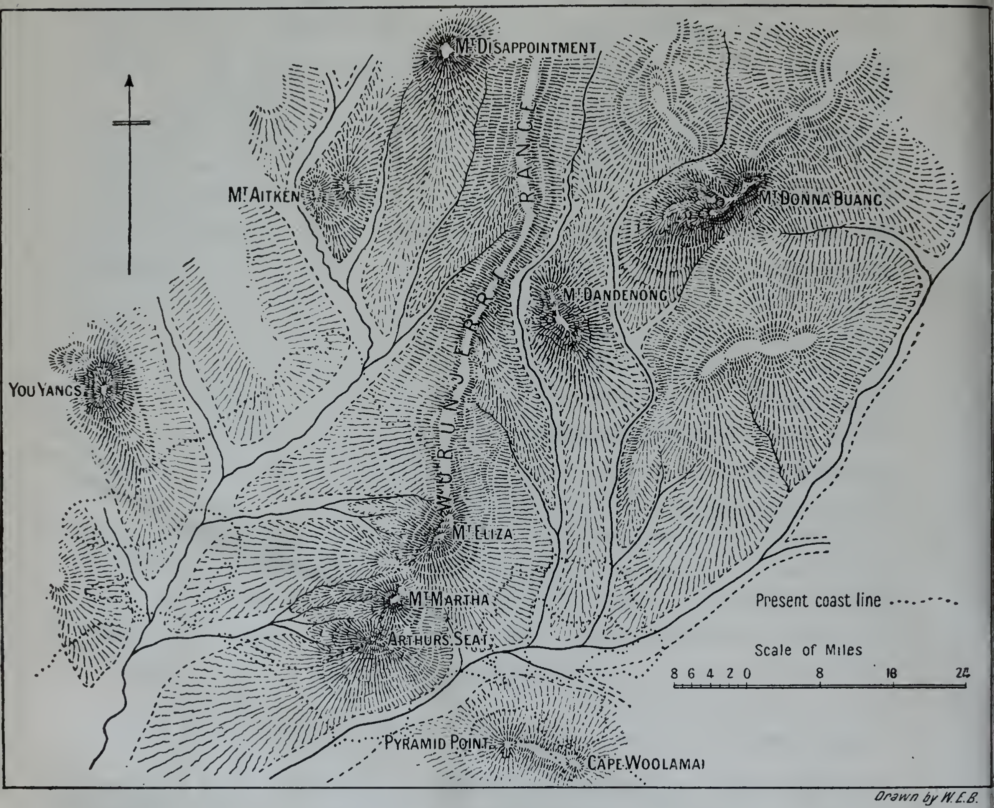


Fig. 6.

A stage in the development of the intermediate cycle some time after the cessation of volcanic activity. Note that the pre basalt streams are on the watersheds (infilled valleys) between the streams of the intermediate cycle.

The rate of cutting back of the lateral streams was regulated, in the first place, by the extensive lava field to the south, over which all streams had to pass, and, in the second case, by infilled tributaries which formed smaller confined lava fields at an angle to the main field, at irregular intervals throughout its length. A stream cutting back and encountering an infilled tributary worked along the tributary lava field until by vertical erosion and sapping the tributary lava field was breached; this usually occurred at or near the main confined lava field.

It is not to be assumed that lateral streams did not immediately form along the whole length of the main infilled valley. They existed from the first as streams of steep and variable gradients, broken with falls, rapids, and shallows, particularly where the tributary confined lava fields joined the main confined lava field.

The added force to the main lateral, once an infilled tributary had been breached, was considerable, and accelerated breaching further back. The breach soon widened, and the detached tributary field became more and more isolated. Many detached and isolated residuals of small dimensions have had the relation of an infilled tributary to the main confined lava field. The best examples are to be found to the east of Pakenham and the north of Gembrook. They have not, as far as I am aware, any particular names.

Where a tributary of relative importance joined the main stream, particularly towards its head waters, the lateral streams on the outer edges of the lava became the main laterals, and those on the inner edge were suppressed or became tributaries. (Fig. 7.) This has probably occurred in the vicinity of Broadmeadows, where two Pre-Older Basalt streams had their confluence, one from the direction of Romsey and the other from Wallan.

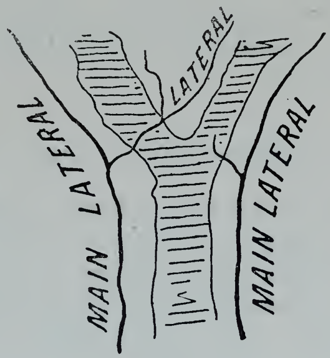


Fig. 7.

Lateral valleys at the confluence of infilled valleys.

Minor laterals.

The erosion of minor laterals on the talus slope between the main lateral and the receding edge of the lava is an important and characteristic feature. They commence when and where the talus slope has assumed such a low gradient that underground and meteoric waters cut in a diagonal direction across it; they are particularly apt to form where the residual is altering its general trend, and have a tendency to attack the residual on both its concave and convex sides. The cutting back of a minor lateral is materially assisted by the talus boulders, which accumulate in the slightest runnel and particularly on the step or flat at the edge of the lava. This step or flat is a noticeable feature near all residuals, and is due to the gouging effect of the heavier talus boulders. The valleys crossing the Gippsland Road between Wilson's Quarry at Berwick and the Narre Warren Creek have all been carved out by minor laterals. They are due to a concave bend caused by the severance some distance from the main infilled valley of a tributary lava field trending west of Harkaway. The old Elizabeth Street Creek, Melbourne, was a minor lateral; it was formed after the Older Basalt was eroded from the vicinity of its basin, and had its source in the concave side of the Melbourne residual. The upper valley of the Ararat Creek at Upper Pakenham bears a similar relation to the eastern lateral (now captured) of the Upper Pakenham residual.

Besides being important factors in breaching a residual, minor laterals tend to throw light on the sinuosities of the Pre-Older Basalt valleys. The minor laterals in the vicinity of Melbourne seem to indicate that the Melbourne residual occupies a valley which changes its direction in the vicinity of Melbourne from south-east to south-west.

Process of breaching. Cross streams.

It is a seeming paradox that the more graded a lateral stream becomes the more remote is its chance of degrading a residual by lateral planation. The potent factors in reducing and breaching a residual are minor laterals which, cutting back on either side of a bend of a residual, attack it at points in close proximity. This is the prelude to the more drastic action of underground water, which is tapped when the head of the minor lateral saps its way under the reservoir represented by the porous beds of the old infilled valley. The breach, then, is accomplished by sapping due, in the first case, to the effect of meteoric waters, but subsequently to the combined action of both the meteoric and underground waters, aided, from time to time, by the rejuvenation of the laterals. The minor laterals on the east side of the Upper Pakenham residual afford examples of the combined action of meteoric and underground waters. Millane's, Copeland's, Moyle's, Taylor's and other springs all give rise to minor laterals, and it is a noticeable feature that landslips are conspicuous near these springs, showing that the lava has lost its grip on the soft, underlying sediments. The minor laterals are also the channels for the drainage flowing down the steep slopes of the residual; the combined source gives a supply of water that lasts throughout the driest seasons.

When a residual has one lateral approaching maturity more rapidly than the other, the weaker one is sooner or later captured by the stronger one. For a certain distance downstream from the breach, the weaker residual is reversed. The eastern residual of the Lilydale residual is a case in point. (Fig. 5.) The hard quartzites in the vicinity of Cave Hill so retarded the formation of the eastern lateral, that Brushy Creek, the western lateral, captured it near where the Yarra flows across the north end of the residual. The eastern lateral valley is now occupied by three distinct streams, namely, Steel's Creek, flowing south through the breach, Olinda Creek (which at one time had its source in the Cave Hill quartzites) flowing north, also through the breach, and the Mooroolbark Creek, flowing both north and south on the south side of the Cave Hill quartzites. It is probable that the eastern lateral of the Lilydale residual never at any time assumed the characteristics of a strong lateral, owing to the hard flanking dacite rocks of the Mt. Dandenong massif.

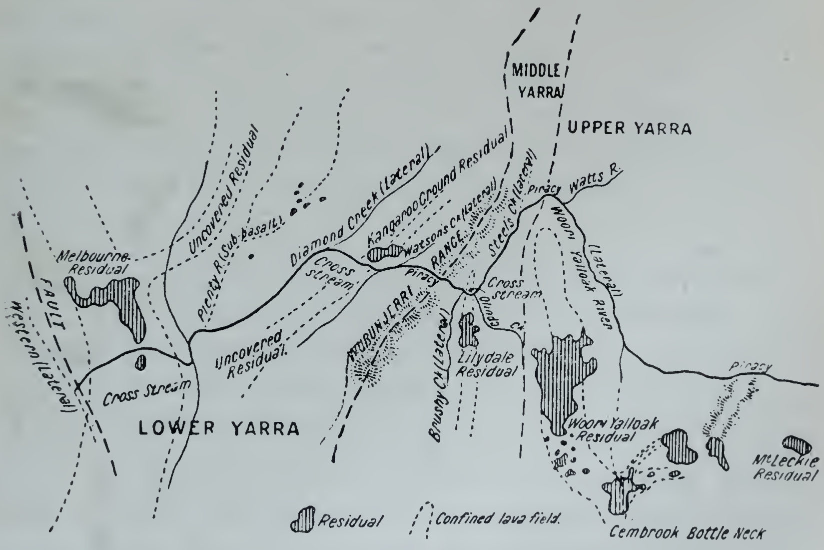


Fig. 8.

The accession of strength by breaching and capture to the headwaters of what was originally the weak lateral, is considerable; the stronger lateral also benefits by the capture. The breach becomes wider and wider as the captured head-waters more rapidly approach maturity, and the severed portions of the residual become more isolated.

The important part played by breaching, and the subsequent development of the cross streams, is shown in a typical way by the development of the Yarra (Fig. 5). The movement originally responsible for the breaching of the Melbourne residual in the vicinity of Melbourne occurred along a fault line parallel with the east side of Port Phillip Bay. Along this line of weakness at a later date the fault block of the Bay itself moved. The eastern lateral of the residual was diverted through the breach, and the subsequent rejuvenation extended along it and all its tributaries. A tributary of the eastern lateral was the Plenty River of the period, and an important tributary of the Plenty River was Diamond Creek, the western lateral of the Kangaroo Ground residual. The eastern lateral of that residual, viz., Watson's Creek, was diverted through a breach into Diamond Creek and rejuvenated. Subsequently the Wurunjerri Range was breached by a tributary of Watson's Creek, and the basin of the Middle Yarra diverted through the breach. The middle Yarra, previous to its diversion, found an outlet to the south of Lilydale either through the Lysterfield Gap or Dandenong. The immediate effect of the diversion was to reverse the direction of part of this southerly trending stream, so that we now have the western lateral of the Lilydale residual (Brushy Creek) flowing northwards, not southwards.

The breaching of the Lilydale residual and the subsequent capture and rejuvenation of the head-waters of the eastern lateral have been referred to (p. 147 ante). Belonging to an earlier period than the series of breachings and rejuvenations, just described in the development of the Lower Yarra, is the system of breaching and rejuvenation in the basin of the Middle Yarra. The eastern lateral of the Lilydale residual, rejuvenated, was powerful enough to breach the Woori Yallock residual, which resulted in the diversion of the Watts and the Woori Yallock River, which for a short time at the inception of the Intermediate cycle, had a southerly trend. The rejuvenation resulting from the breaching of the Woori Yallock residual probably accomplished the breach at Warburton, which resulted in the diversion of portions of the laterals of the infilled valley from the vicinity of Mt. Buller to Flinders.

From the fact that it is a series of laterals and breaches the Yarra has a circuitous trend, but the breaches give its valley a dominant gradient to the west. The Yarra and the upper portion of the Goulburn are the only rivers in Victoria that have valleys with a distinctly westerly trend. The Latrobe, on the other hand, is the only river with a decidedly easterly trend. The three streams mentioned undoubtedly owe this peculiarity to their composite character; they consist of portions of laterals and cross streams pieced together. As evidence of the great strength of the breaching streams, it is suggestive that the Mt. Leckie residual trends east and west parallel to the cross streams of the Upper Yarra and Latrobe. The "high level lead" beneath, I am informed by a miner who has prospected it, falls to the south, which is to be expected from the trend of the confined lava field.

Residuals with resistant rocks on one side.

It has been observed under the heading of resistance, that the more resistant rocks of the areas are those altered at the contact of the Palaeozoic sedimentary and igneous series. The relative resistance of the altered rocks decreases away from the actual contact until the normal sediments are reached; there is therefore in the metamorphic zone, a gradation from the most resistant to the least resistant rocks. Where two contacts converge and are in close proximity a bottle-neck is formed, and all streams between the converging contacts are forced to seek an outlet through this bottle-neck. The Flinders bottle-neck was the main outlet for the Pre-Older Basalt streams of the Western Port system. It was formed by the converging contacts of the Arthurs Seat and Pyramid Point granite series. The Gembrook bottle-neck was formed by the converging contacts of the Dandenong and Pakenham granitic series.

The tendency of some Pre-Older Basalt streams was to cut back along the normal sediments immediately outside the aureole of metamorphism; as a consequence one side of their valleys was flanked by rocks that increased in resistance until they were among the most resistant rocks of the area, while those on the other side were among the least resistant. At other localities hard dacites are on one side of the valley and soft sediments on the other. In the development of laterals after a valley of this kind has been occupied by lava, the erosion of the lateral on the hard rocks is retarded or suppressed, but the lateral formed on the soft rocks on the other side develops quickly. This is due to the fact that the latter is the outlet for the whole of the drainage of the infilled valley.

In the bottle-neck, however, the lava is flanked on both sides by hard rocks—actually harder than the infilling lava; consequently, all streams developed later than the lava have to seek an outlet over it. The resulting retardation of the development of the system further back makes them easy captures to adjoining systems.

A good example of the retarding effect of a bottle-neck and its consequences is the sequence of events leading up to the capture of the eastern lateral—Woori Yallock River (so-called) of the Woori Yallock residual. Two confined lava fields converged southwards towards the Gembrook bottle-neck, the western one at the contact of the Mt. Dandenong dacite massif and the Dandenong granitic series, and the other or eastern one along the Pakenham granitic series. The converging contacts were only about a mile apart a little to the south of Gembrook, where the two confined lava fields joined. The gradients of the converging lateral streams were regulated by the lava in the bottle-neck over which they had to pass. Their development was comparatively slow and their general levels were always higher than the adjoining system of the Middle Yarra. When the streams of the latter system were rejuvenated, a tributary of the eastern lateral of the Lilydale residual breached or cut back round the lava occupying the westernmost valley of the Upper Yarra system and captured its eastern lateral. (Fig. 8.) The Watts River—the upstream portion of the captured lateral—was diverted through the breach, and the downstream portion was reversed as far as the Gembrook bottle-neck, and likewise diverted through the breach. Moreover, the lateral formed along the easternmost confined lava field converging towards the Gembrook bottle-neck, has been captured by the reversed lateral of the western confined lava field.

Ultimate configuration of residuals.

The frequent rejuvenation of the laterals and the consequent widening of the breaches tends to increase the isolation of the residuals, and at the same time reduce their extent and bulk. The shape shows the degree of encroachment of erosional forces, and may be illustrated by a fairly complete set of examples. (Fig. 9.)

The greater axis of the residual almost invariably lies between S 15°E. and S 15°W, suggesting that the trend of the Pre-Older Basalt valleys coincides with a system of erosion governed by the strike of the Palaeozoic sediments. The few exceptions may be explained by local irregularities due to unequal resistance or the development of cross streams following breaching. A stream cutting across the metamorphic zone does so in the line of least resistance, that is, straight across it. The striking eastern prolongation of the Gembrook residual is a case in point.

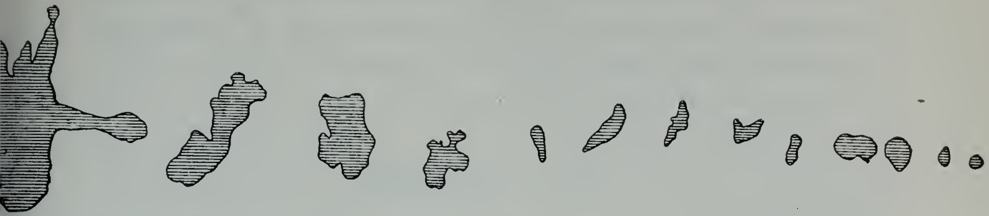


Fig. 9.

Configuration of actual residuals showing variety of form. All drawn to same scale and oriented.

The section of a residual with only one lateral developed represents that of a bluff. The steep ascent from Cockatoo to Gembrook represents the ascent of such a residual; and when the ascent has been accomplished, the railway line runs along a comparatively level surface at the top of the residual. The last portion of a residual to succumb to erosion is usually more or less circular.

"Uncovered residuals."

A physical connection between two residuals separated by the valleys of cross streams may be recognised by "uncovered residuals," or the spur or range left after the lava covering has been removed. (Fig. 8.) If they are in the valley of a cross stream, their general trend is towards the cross stream. An example of such, which forms an important link in connecting up the valley of the stream flowing from the vicinity of Mt. Buller to Flinders, is the ridge (part of the Main Divide) trending south-westerly from Woods' Point. The Yering Gorge described by Mr. Jutson[1] has probably been cut through an uncovered residual in the trail of the Lilydale residual. The watershed between Dandenong and Burwood Creeks is probably another example. There are numerous typical examples to be seen in the Western Port area on the slope from the Yarra watershed towards the Koo-wee-rup Swamp.

The southern watershed of the Yarra basin and the Main Divide are the only east and west trending ranges on the area under consideration. They belong to the period when the cross streams

---

1 Vide Bibliog., No. 12.

became the dominant factors in the erosion of the systems, and are essentially ranges formed by erosion. When the lava in the Gembrook bottle-neck disappears the drainage of the Middle Yarra may again find an outlet in this direction. The watersheds between the lateral valleys are still the most conspicuous ranges and spurs of the systems, and trend north and south; even in the Yarra basin the trend of the ridges between the laterals on its south side disclose to some extent a southerly gradient.

Isolation of residuals.

One has only to travel in the direction of the infilled valleys to realise that residuals are separated by the valleys of the cross streams, and that when allowance is made for the amount of lava removed by them, an approximate idea of the length and extent of the confined lava fields may be formed. For instance, if we take the confined lava field that occupied the valley of the Pre-Older Basalt stream that originated somewhere near Mt. Buller and trended towards Flinders, we encounter a number of residuals isolated by east or west valleys—the valleys of the cross streams. In the trend of this ancient valley, the Mt. Buller residual is separated from Klingsporn's residual by the Howqua. Klingsporn's residual is separated from the Woods Point residual and "uncovered residual" by the valleys of the Jamieson and Goulburn, the Woods Point residual and "uncovered residual" is separated from the Mt. Leckie residual by the valley of the Yarra, the Mt. Leckie residual is separated from the Neerim residual by the valley of the Latrobe, and the Neerim residual is separated from the Drouin residual by the valley of the Tarago. Southwards from Drouin the lava may exist as a connected sheet; at any rate, it belonged to an extensive lava field with much of the erosion hidden by block faulting and masked by recent deposits. Other examples could be cited, but the geological map of a district will disclose more at a glance than a detailed description.

When the point of time at which any of these cross streams actually breached the confined lava plain is determined accurately, a connected geological history of not only the evolution of the stream systems, but also the accumulation of deposits in their valleys will be possible.

The repeated rejuvenation of the streams that have accomplished the breach has in many cases been the result of block faulting, but caution is necessary lest one should ascribe to a fault what may be due to differential erosion. Although, for example, the Dandenong-Cape Schanck fault may have been, to some degree, responsible for the encroachment of the streams belonging to the Port Phillip system into the Western Port area in the vicinity of Narre Warren and Cranbourne, by far the greater factor was the differential erosion of the two systems. The hard lava in the Flinders bottle-neck, over which all the drainage of the Western Port system had to pass, so retarded its development that the comparatively rapid development of the Port Phillip system made capture relatively easy. The Wurunjerri Range[1] being composed of soft sediments in the vicinity, Dandenong was the most probable locality for breaching.

III.—Evolution of a Residual from an Extensive Lava Field.

The Western Newer Basalt Lava Field.

On the extensive and comparatively young Newer Basalt lava field of Western Victoria, many of the drainage channels still follow the courses assumed by them at the cessation of volcanic activity and their disposition in relation to the softer rocks beneath the lava is quite arbitrary. There are areas, however, where the softer sediments along the Pre-Newer Basalt watersheds have been exposed by vertical erosion and where sapping has commenced along the line of least resistance, that is along these watersheds. A portion of the lava plain north of Melbourne affords a typical example. The Saltwater River has sapped its valley along the old watershed between the Pre-Newer Basalt valleys coming from the directions of Romsey and Wallan, and joining in the vicinity of Bulla. Both the Saltwater River and Emu Creek will ultimately become laterals (Fig. 2) to a residual, the protective covering of which is lava belonging to the Newer Basalt. In the central western area of Victoria there are many examples of confined lava fields belonging to the newer volcanic series, where laterals are cutting back on the softer rock along their edges, and all the erosional factors are operating to produce the residual just as they have in the Western Port area from the older lavas. The confined lava plains of the western area extend northwards for many miles but southward for a limited distance to where they join the extensive lava field of Western Victoria south of the present Divide. The circuitous line marking this junction is where what is here

---

[1] Vide p. 157, post.

termed the "cross-lateral"[1] will form, and is the probable direction of a great valley to be developed perhaps under the same condition as that much earlier valley referred to by Prof. Gregory[2] as the Great Valley of Victoria.

The residual is the outcome of the erosional processes on both the extensive and confined lava fields, but peculiar considerations affect the transition from each type of lava field. In the case of the confined lava field (Fig. 1) the lateral streams are formed on the softer rocks at the edge of the lava, and relatively near the infilled stream; but on the extensive lava field (Fig. 2), the lateral streams may form along uncovered watersheds anywhere between the infilled streams. In other words, from a confined lava field, laterals form comparatively close parallel valleys, and the resulting residuals are restricted in size, while the laterals developed on an extensive lava field are usually far apart, and extensive residuals are the result. Moreover, the flanking softer rocks exposed by a lateral evolved from an extensive lava field are always below the lava covering of the residual, which is not the case in the development of a residual from a confined lava field, where, on the opposite side of the lateral valley to the residual, they are both above and below the level of the lava.

Apart from these and other minor distinctions, striking parallels in development are forthcoming by a comparison of the still youthful erosion of the western cycle from the newer volcanic series, and the mature erosion of the eastern cycle from the older volcanic series.

Development of a Residual from an Extensive Lava Field.

Streams that formed wholly on an extensive lava field flowed in the direction of the gradient which, according to Harker,[3] is very slight. Although their initial directions were dominated by this gradient, their once seemingly aimless courses were due to such factors as sag, the edges of flows, faults, etc. When, however, one of these streams had cut down to the underlying less resistant rock, the factors that governed its development may be summed up in the following :—

(a) They cut back along the line of least resistance, i.e., along the line of least thickness of overlying lava.

---

1 Vide p. 155, post.
2 Bibliog., No. 4
3 Vide Bibliog., No. 6.

(b) The least thickness was usually along the pre-basalt ridges and watersheds.

(c) When the line of least resistance was reached cutting back and sapping commenced along it, and a new valley was initiated—that of a lateral of a prospective residual; the old stream, by domestic piracy, became a tributary to this new stream.

It is apparent, therefore, that the valleys formed on an extensive lava field, though at first seemingly arbitrary as regards direction, eventually carve out valleys parallel to the sub-basalt (pre-basalt) valleys, but on the watersheds between them. This is the beginning of a process of isolation. The residuals are formed by the operation of the same erosional factors as in the case of the confined field and the evolution proceeds on precisely similar lines.

Junction of Confined and Extensive Lava Fields.

Cross Lateral.

Arising from the fact that the lateral streams of a confined lava field cutting back on the soft rocks at the edge of the infilling lava, are relatively close compared to the lateral streams formed on an extensive lava field, the vicinity of the junction of a confined and extensive lava field is characterised by typical and important changes in the conditions of erosion. It is the critical locality where, when erosion has reached a certain stage, one class of lateral crosses over and assumes the characteristics of the other. This is usually effected by its cutting round the spur of softer rocks flanking the confined field,[1] to the line of least resistance on the extensive field, that is, in the direction of this spur under the lava.

This critical locality affords perhaps the most advantageous conditions for piracy in the whole drainage system. The lateral streams of both classes are in juxtaposition, and the distance between them has in places been halved—in fact, a portion of any possible cross stream with piratical tendencies has been formed by the crossing over of the lateral. Such a stream precipitated, say, on the relative upthrow side of a fault parallel to the trend of the lateral streams, or encroaching from an adjoining more powerful system, finds this locality a vantage point. As streams of considerable length are usually involved, the piratical stream receives a powerful accession of strength.

---

1 At this critical point gradient sometimes overcomes resistance and the lateral streams of the confined lava fields maintain their directions.

From the fact that the lavas of Western Victoria are comparatively recent, and those of Eastern Victoria relatively old, typical instances of the cross-lateral in all its stages are difficult to select. Perhaps the confluence of the confined and extensive lava plains to the south of Ballarat provides as good an example of the preliminary conditions leading to the formation of a cross-lateral, as may be found. (Fig. 10.)

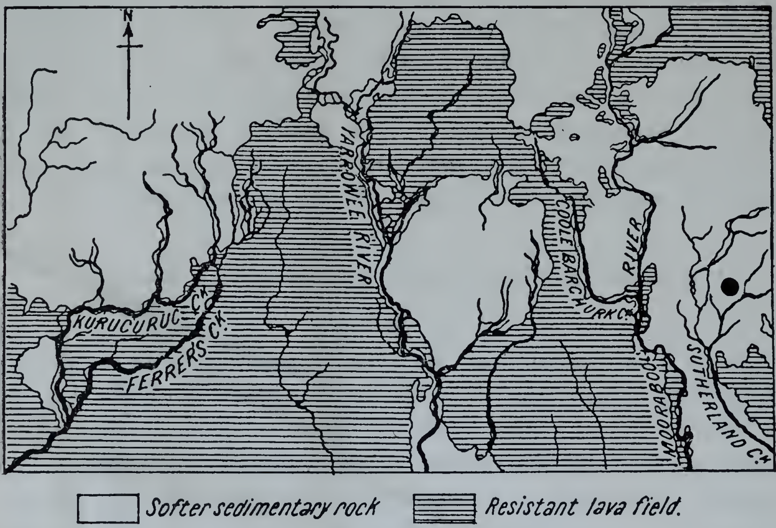


Fig. 10.

Typical conditions for the subsequent development of the cross-lateral junction of confined and extensive lava fields, south of Ballarat. Scale 8 inches to 1 inch.

The Hallam Creek furnishes a typical example of a mature cross lateral, Assisted by the hard rocks at Flinders, which retarded all streams seeking an outlet in that direction, strengthened by the rapid and unretarded erosion of the Port Phillip system, and rejuvenated by the Cape Schanck-Dandenong fault, the head-waters of a stream belonging to the Port Phillip system have cut back to the east of Dandenong, and encroached on and captured all the laterals of the Western Port system up to and including the eastern lateral of the Berwick residual, and possibly even further afield. It has diverted the lateral streams coming from the north, and reversed the direction of their continuation to the south. The streams concerned are the Narre Warren Creek (the original length of which is shown on Fig. 6), two laterals (in part) of the Cranbourne residual, which have been reversed, and some minor laterals.

Significance of the Cross-lateral.

The speculations arising from a consideration of the immense power gained by the cross-lateral by successive captures, are important and interesting. It is suggested that the Great Valley of Victoria[1] may have had its beginning in this way, and although crustal movements, block faulting and other factors may have ultimately contributed to its formation, portion of it at least east of Melbourne may be thus accounted for. How powerful the Hallam Creek actually was may be conceived by the fact that its flood plain is in many parts a mile wide, although, through beheading, it now carries a mere trickle. The part played by this stream in the sedimentation of the Carrum Swamp was considerable.

IV.—Distribution of Residuals and Classification of Valleys.

Confines of the two systems.

The Older Basalt residuals of the area dealt with in this paper are along the trend of Pre-Older Basalt valleys (Fig. 3) belonging to two well-defined systems, namely, the Western Port and the Port Phillip. At the cessation of volcanic activity the watershed separating these two systems extended from Arthur's Seat to Frankston, and was due to the resistance offered by the metamorphic rocks at the contact of the Palaeozoic sedimentary and igneous series. Between Frankston and Dandenong it was composed of less resistant sediments, probably of Palaeozoic age. From Dandenong it followed the metamorphic rocks, to the west of that town, to Wheelers' Hill, thence to Vermont, thence through Ringwood to the quartzites running parallel to Brushy Creek, Its continuation was the line of hills formed by these quartzites through Mt. Graham, Big Hill, Conical Hill, and Bald Hill, to about eight miles east of The Gap, beyond which point it has not been defined. This watershed has been referred to in this paper as the Wurunjerri[2] Range. Parts of the drainage system of the Yarra referred[3] to by Prof. Gregory as the basins of the Middle and Upper Yarra are here assigned to the Western Port system.

1 Vide Bibliog., No. 4.

2 The Wurunjerri tribe inhabited the Yarra basin.

3 Vide Bibliog., No. 4.

Residuals of the Western Port system.

The residuals along the valley of the main pre-Older Basalt stream of the Western Port system, from Mt. Buller to Drouin, have already been mentioned (p.   ante). The Drouin residual has been truncated southwards by a block fault. At Lang Lang, south of Drouin, the basalt is 436 feet below the surface, but it again appears at the surface on the mainland at the north-east corner of Western Port Bay. From the last mentioned point to Flinders and Cape Schanck, it probably exists as an unbreached sheet. This stream is identical in direction with Prof. Gregory's Tarago, but since the present Tarago is much more recent, and, moreover, is a cross stream, another name would be more appropriate, and it will be referred to in future as the Flinders.

A large tributary of the last mentioned stream had its source somewhere north of the Woori Yallock residual, and was probably identical in its head-waters with the Watts. Its course is represented by the "uncovered residual," of Steel's Range, the Woori Yallock residual, the Gembrook residual, the Pakenham residual, and by a line of conspicuous "uncovered residuals" disappearing into the Koo-wee-rup fault block towards the trunk stream. Above the Gembrook bottle-neck this tributary received a tributary from the north-east; it originated on the westerly slope of Mt. Donna Buang.

Another large tributary had its source north of the Kinglake Gap and is probably represented in its head-waters by the reversed Yea River. South of the Kinglake Gap its course is represented by the uncovered residual between Steel's Creek and the parallel valley to the west, and still further to the south, by the Lilydale residual. It then trended southwards through the Lysterfield Gap below which it is represented by the Harkaway, Berwick and Beaconsfield residuals. It joined the trunk stream somewhere in the vicinity of French Island.

A smaller tributary had its source to the north of Cranbourne, flowed in the vicinity of the Cranbourne residual, and joined the main stream or a tributary of it in the vicinity of French Island.

There are many smaller residuals which from their configurations, positions and characteristics lead one to believe that they have been developed from infilled tributaries or by cross streams.

Residuals of the Port Phillip system.

The connection between the Melbourne and Bellarine residuals is problematical, but it is certain that an important stream received tributaries from different portions of the system and passed southwards over the Bellarine Peninsula. The extension north of the Bellarine residual may be traced under the waters of Port Phillip Bay by the bathymetrical contours. The trend of the stream is represented by the Older Basalt lava, east of Sunbury, Bulla, Broadmeadows, Essendon, Melbourne and South Melbourne, all situated on the Melbourne residual. The western lateral of the Melbourne residual lies beneath the Newer Basalt extensive lava field, but its eastern lateral is now a confined Newer Basalt lava field, and may be easily located by the laterals forming on either side. (Fig. 4.)

Apart from the Melbourne and Bellarine residuals, the Kangaroo Ground and some smaller residuals are all that remain to show the erosion antecedent to the Newer Basalt.

A systematic classification of valleys.

From the several types of erosion described, a tentative classification of many of the streams, according to the factors that started the formation of their valleys, may be attempted. Starting with the oldest, it is proposed to adopt the following classification :—

(1) Pre-Older Basalt cycle.
(2) Older Basalt cycle.
(3) Intermediate cycle.
(4) Newer Basalt cycle.
(5) Post Newer Basalt cycle.

(1) *Pre-Older Basalt Cycle.*

The head-waters of some streams may still belong to this cycle; probably the Watts River is still occupying a Pre-Older Basalt valley. Many of the valleys are still intact below the Older Basalt residual.

(2) *Older Basalt cycle.*

Short cycles which started after each successive flow of the older lavas—in mining phraseology, "false bottoms." It may be found possible to correlate the soft strata between the hard basalt disclosed in the Lang Lang, Phillip Island, Flinders and Cape Schanck bores.

(3) *Intermediate Cycle.*

This cycle is designated "Intermediate," because on the Port Phillip area it covers the stream development during the period between the Older and Newer Basalts. Many of the streams have been repeatedly rejuvenated during that period, but I am guided by the fact that their valleys were first formed at a particular time during the cycle. They may be classified under the system to which they belong.

PORT PHILLIP SYSTEM.

Lateral Valleys—
- Diamond Creek.
- Watson's Creek.
- Gardiner's Creek.
- Lake Connewarre.
- Valleys now occupied with Newer Basalt confined lava fields.
- Yarra (parts).

Cross Lateral Valleys—
- An old valley in the vicinity of Springvale and Clayton.

Minor Lateral Valleys—
- Old Elizabeth Street Creek.
- South Yarra Creek.
- Moonee Ponds Creek (part).

Cross Stream Valleys—
- Yarra, at Melbourne.
- Yarra, south of Kangaroo Ground.
- Western end of Channel of Corio Bay.
- Several valleys infilled with Newer Basalt.

WESTERN PORT SYSTEM.

Lateral Valleys—
- Woori Yallock Creek.
- Bunyip River.
- Narre Worran Creek.
- Cardinia Creek.
- Deep Creek (part).
- Steel's Creek.
- Olinda Creek (part).
- Brushy Creek (part).
- Mooroolbark Creek (part).
- Dandenong Creek (part).
- Clyde Creek.
- Cranbourne Creek.
- Hallam Creek (part).
- Yarra (parts).

Cross Lateral Valleys—
- Hallam Creek (part).

Minor Lateral Valleys—
- Creeks crossing Gippsland Road between Narre Worran Creek and Berwick residual.
- Several tributaries of Woori Yallock River. Other unnamed creeks.

Cross Stream Valleys—
- Yarra, north of Lilydale residual.
- Brushy Creek, south of Lilydale residual.
- Yarra, a little west of confluence with Watts.
- Yarra, upstream from Warburton.
- Headwaters of Latrobe River.
- Tarago River.
- Some channels of Western Port Bay.
- Ararat Creek (head waters).

(4) *Newer Basalt Cycle.*

Short lived cycles between successive flows of newer lavas.

(5) *Post Newer Basalt Cycle.*

PORT PHILLIP SYSTEM.

Lateral Valleys—
- Yarra, between Heyington and Fairfield.
- Merri Creek (part).
- Darebin Creek (part).
- Moonee Ponds Creek (part).
- Saltwater River.
- Riddell's Creek.
- Hovel's Creek (part).

Valleys formed on Extensive Lava Field—
- Kororoit Creek.
- Werribee River.
- Skeleton Water Holes.

Synopsis of Paper.

The lava residual is the result of the greater resistance to erosion of basaltic lavas compared to that on the softer rocks contiguous to them.

The development of the Older Basalt residual is characterised by three readily defined cycles—namely, (1) the Pre-Older Basalt cycle, (2) the Older Basalt cycle, and (3) the Intermediate cycle. The development of the Newer Basalt residual is also characterised by three cycles—(3) the Intermediate cycle, (4) the Newer Basalt cycle, and (5) the Post Newer Basalt cycle.

The Intermediate and Post Newer Basalt cycles during which the actual development of the residuals took place were, at their inception, characterised by two types of lava field, formed during the preceding cycle, namely—(a) the confined lava field which was contained within the watersheds of the Intermediate cycles, and (b) the extensive lava field where the lava escaped the limits of these watersheds.

The development of a residual from a confined or extensive lava field proceeded, at its initial stages, on somewhat different lines. From a confined lava field, a residual was developed by lateral streams on the soft rocks at the parallel edges of the lava; from an extensive lava field, the development was by lateral streams on the